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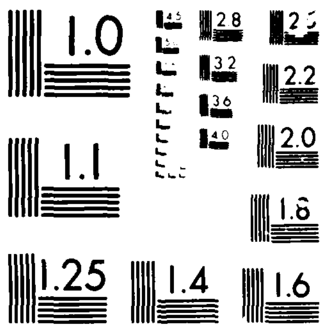


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# A DESIGN PROCEDURE FOR MOORINGS WITH RESTRICTED WATCH CIRCLES

by Thomas J. O'Boyle and Theodore P. Jones

Ocean Engineering and Construction Project Office
Chesapeake Division, Naval Facilities Engineering Command

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## ABSTRACT

This paper demonstrates a rational process for the design of moorings which require restricted watch circles. A systematic approach relating buoy deflection, water depth, anchor drag, leg pretension and other physical parameters is presented. The result is a pretensioned mooring which meets the performance requirements of a reduced watch circle and allows for the unknown anchor drag distances which arise from the geotechnical uncertainties of the site.

This approach has been successfully used by the Navy to design and install moorings for ammunition barges in Puget Sound, WA. It is not covered in standard Navy mooring design manuals, nor is it detailed in other port facilities design texts. Previous methods have not addressed the relationship between anchor drag and pretension forces. This method is an invaluable aid to the designer of a restricted watch circle mooring since it can easily be coded for a hand held calculator or a computer.

## 1. INTRODUCTION

The Officer in Charge of Construction, Naval Facilities Engineering Command, TRIDENT (OICC, TRIDENT) was tasked to provide three fleet moorings on the west side of Indian Island, Puget Sound, Washington. These moorings were Phase I of a total of six moorings to be installed at the Naval Undersea Warfare Engineering Station (NUWES), for securing YC and YFN ammunition barges. Due to unusual site characteristics and the tight positioning constraints of the Explosive Safety Quantity Distances (ESQD) it was imperative that the moorings be implanted in precise locations and that the mooring circles swept by the anchored barges be of minimal dimensions. See Figure 1.

In June 1978, OICC TRIDENT requested that the Ocean Engineering and Construction Project Office, Chesapeake Division, Naval Facilities Engineering Command (CHESNAVFACENGCOM, FPO-1) perform a design review and determine the installation options for the first three moorings (Phase I). The remaining three moorings were to be designed in FY82 and installed in FY83. The moorings were designed to be permanent installations and hold the barges in

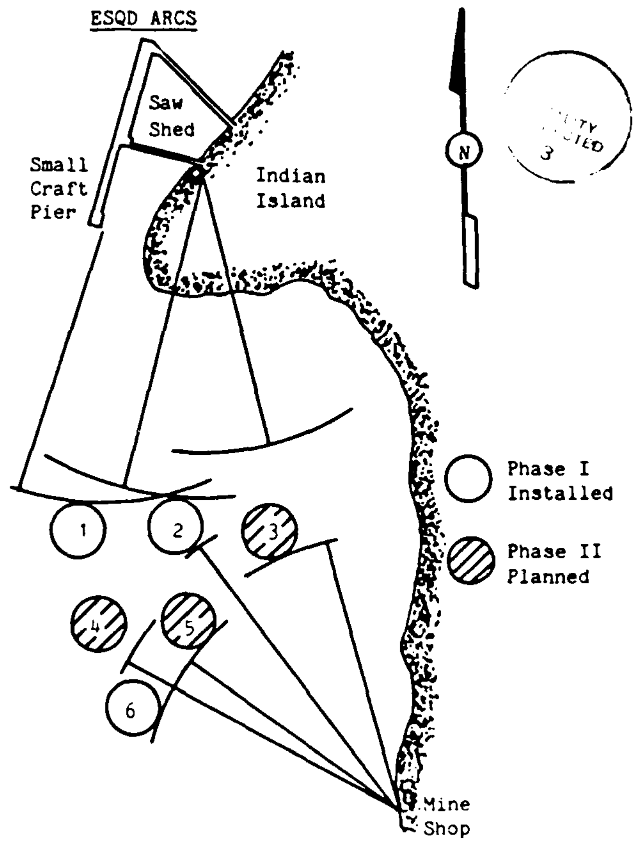


Figure 1

a 100 mph wind with a nominal 2 knot current resulting in a 12 kip design load. The mean low water depths at the Phase I mooring locations varied slightly around 90 feet and the available bottom data indicated approximately 90 feet of zero blow count material below the mud line.

Prior to requesting that FPO-1 perform a design review, OICC TRIDENT procured the mooring materials based on the available information (90 feet of water plus 90 feet of zero blow count material).

In brief, the problem was to design a mooring for 90 feet of water using only the material already procured that could be accurately and cost effectively installed and, when under full design load, would have a buoy watch circle of 50 feet or less.

## 2. PHASE I

We wanted the final design for Phase I to remain as close as possible to a standard fleet mooring design, such as found in the Navy's Design Manual, NAVFAC DM-26 (July 1968). See Reference 1. All the Naval Public Works Centers (PWC) that install and service the existing fleet moorings use DM-26 as their guide. The PWC riggers are familiar with the configurations and connections of the standard mooring types. Also, the installation procedure would be familiar to PWC deck personnel and could be accomplished using Government assets. The installation would be safer than if a unique design was used. The main disadvantage of using the standard design for this installation was the large watch circle that is associated with a long riser. This large watch circle would be in excess of the allowable 50 foot maximum. The mooring configuration options we considered were: (a) a two point mooring; (b) a telephone-type mooring; (c) a free-swinging, shortened riser mooring. The two point (bow-stern) mooring would restrict the barge movement the greatest, but would require the procurement of more material. The telephone-type mooring brings all the anchor legs up to the buoy. This arrangement reduces the watch circle efficiently, but in this water depth, results in excessive weight in the water column. The buoys available on island were not large enough to support this much weight. The free-swinging mooring configuration was choosen as the best option.

A standard free-swinging riser-type mooring would have a buoy watch circle greater than 70 feet in this water depth. We had to modify this configuration to reduce the watch circle and keep the vertical load on the buoy low enough to maintain at least 18 inches of freeboard under a no load condition. We decided to achieve this by putting a pretension on each leg at the ground ring. See Figure 2. This pretension would be generated by lifting the ground ring a distance from its standard position near the bottom, thus creating a catenary in each leg.

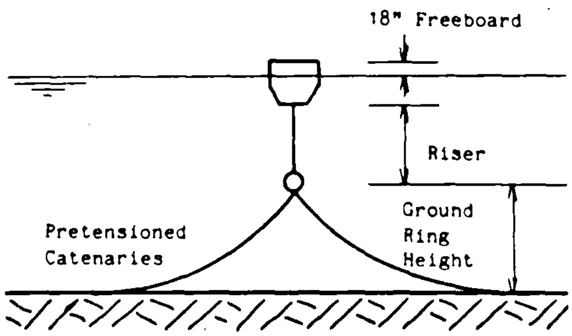


Figure 2

To aid in the numerous calculations, we used a programmable TI-59 calculator for Phase I. Because the programs written on the TI-59 could only handle one horizontal force applied to a catenary at a time, several preliminary loads had to be calculated before the final catenary model could be used. This final model simulated the mooring as a single leg made up of the ground chain and riser. The pretension applied to the ground ring and the calculated environmental horizontal load on the buoy were combined and applied at the buoy only.

The first calculations determined the vertical force needed to lift one end of a ground leg. We made the following assumptions:

1. the projected horizontal distances from the anchor to the ground ring remained constant for each series of vertical forces we applied,

2. the anchor did not move for each series of vertical forces,

3. the chain laid flat on a level bottom,

4. the chain started out straight and tight from the anchor to the ground ring,

5. the chain did not sink below the mud line, and

6. all the load was applied to a single leg.

To account for the unknown anchor drag distance in this zero blow count material, we shortened the projected horizontal catenary length in increments. We created a "synthetic riser" equal in length to the increment we removed. See Figure 3. The combined length of the synthetic riser and the chain on the bottom at zero load equalled the same constant for each anchor drag distance. Figure 4 shows the vertical load due to a single leg at equilibrium for a range of anchor drag distances and ground ring heights.

The vertical force calculation for a single leg was multiplied by 3 to determine the combined effect of all of the legs. We added a nominal riser weight to calculate the total vertical load on the buoy. This allowed us to remove many trivial cases from further consideration. The vertical force on the buoy had to be investigated for the full tidal range. We assumed the ground ring height would vary from +10 feet to -3 feet about its position at MLLW. For example, if the ground ring was 30 feet off the bottom at MLLW, the vertical load on the buoy was calculated for a ground ring height of 40 feet to check for overloading at high tide.

The relationship between the horizontal pretension force at the ground ring and the ground ring height for various anchor drag distances is given in Figure 5. These values are crucial in the final deflection model for the system.

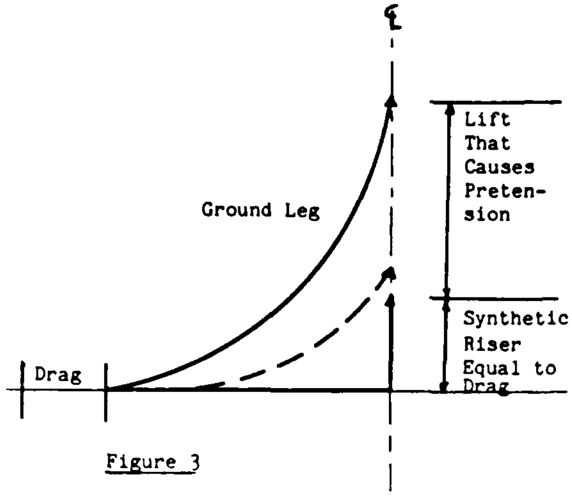


Figure 3

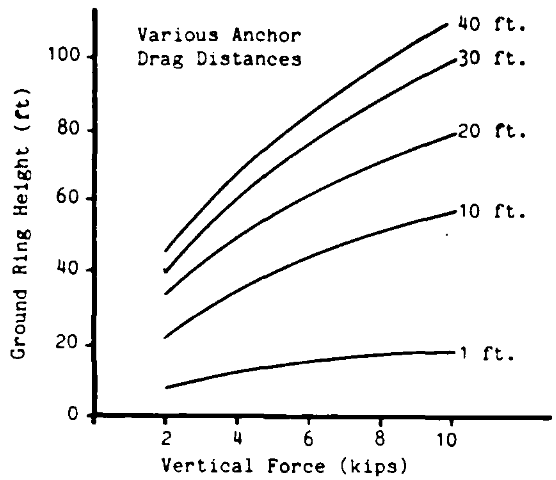


Figure 4

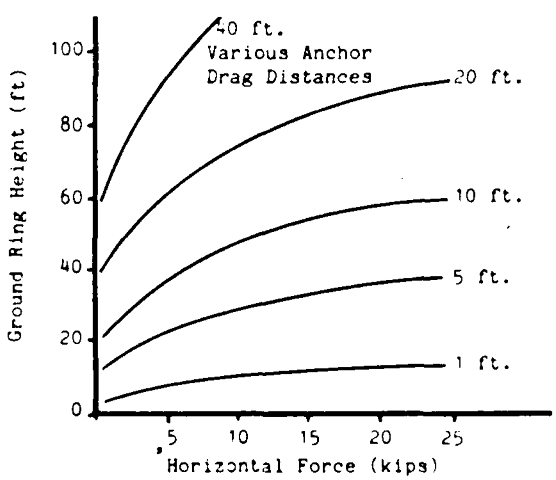


Figure 5

As mentioned previously, the TI-59 calculator can handle only one horizontal force applied to the catenary at a time. The model we used combined the pretension load on the ground ring and the horizontal load on the buoy and applied this load to the catenary at the water's surface. We checked the effect on the accuracy of the deflection calculation due to the combination of the two applied loads as follows. First, the deflection of a catenary formed by only the chain from ground ring to anchor was calculated for a horizontal force equal to the pretension plus surface horizontal forces for a water depth equal to the ground ring height. Second, the catenary was modified to include the riser from ground ring to surface, the same load was applied at the surface and the deflection of the ground ring was determined. These two deflections were approximately the same. This method resulted in a conservative watch circle estimate because the weight of the suspended chain from the other two legs was neglected. This weight would tend to reduce the watch circle.

Using the above model, we calculated the mooring's displacement from its no load position for a range of buoy loads. We plotted the results of these calculations on two sets of curves. The first curves showed Horizontal Displacement versus Horizontal Force. The horizontal force plotted was only the force at the buoy, not the combined force used for the displacement calculations. The second set showed Horizontal Displacement versus Total Vertical Force on Buoy. We used these curves to decrease the number of acceptable candidates by illustrating which configurations would result in vertically overloading the buoy at full deflection. This was not the same requirement as the 18 inch freeboard minimum at no load.

We then combined the information from the above curves into a set of final design curves. For each reasonable ground ring height, we plotted Anchor Drag versus Horizontal Displacement for various water depths and the associated riser lengths. The final design curves illustrated the critical anchor drag distances where: (a) the ground chain became slack below the ground ring; (b) there was excessive vertical force on the buoy, and; (c) there was excessive horizontal deflection of the buoy. The best ground ring height and riser length could then be chosen based upon the maximum anchor for all tidal depths.

During the design phase of this project, a detailed site survey was conducted of the mooring area, and the bathymetry confirmed a flat bottom. The subbottom profiles indicated the same type of material was present at all the mooring locations, but could not give any indication of the soil strength. Several Vibracores were taken in the area and showed a greenish gray organic material. The only indication of soil strength was obtained during an anchor pull test; the anchor remained on the upper layer of the mud after free-falling through the water column. A line secured to the crown measured the same as the water depth. These field findings strengthened our basic design assumptions and ensured an accurate design.

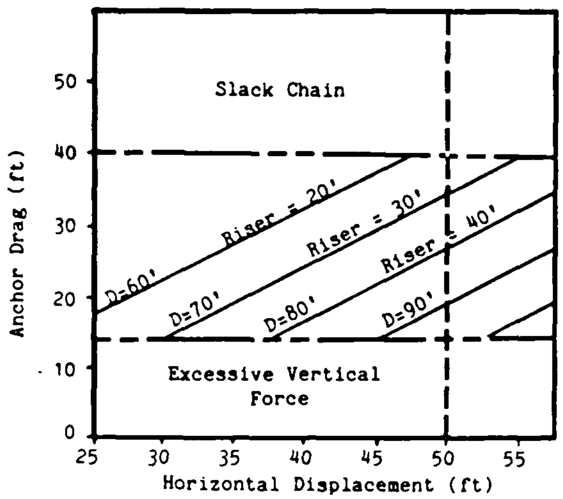


Figure 6

To avoid problems during installation, we kept the design of all three moorings identical. The design called for a three leg riser type mooring. Each ground leg was 430 feet long and was spaced 120° apart horizontally. Each riser was 35 feet long, placing the ground ring 40 feet below the surface. This constant riser length simplified the rigging. We calculated that each mooring would have a watch circle within the 50 foot maximum. The design allowed the following anchor drag tolerances: (a) each anchor would slip at least 15 feet, thus avoiding an excess vertical force on the buoy; (b) each anchor could slip up to approximately 30 feet and the mooring would still have less than a 50 foot watch circle.

The installation method was developed simultaneously with the design to ensure that the installation was feasible and that the assumptions made in the design would not be violated. The following scenario was used to install these moorings. Each buoy was fitted with a 45 foot section of chain that could be removed and a 35 foot riser which were attached to the ground ring. Each leg was laid out on the bottom from the ground ring toward a pre-positioned marker buoy. Each anchor's flukes were welded fully open and control lowered using a crown line so the flukes were pointed down. After all three legs of one mooring were installed, each anchor and chain was pulled radially outward using the crown line. This ensured that the chain was straight and tight. After this pull was accomplished, the buoy was lifted up high enough to allow the 35 foot riser to be secured to the deck and then the 45 foot piece of chain was removed. During the lifting operation the load was measured on a dynamometer secured between the buoy and the crane's hook. Using a graph of the Ground Ring Height versus Total Vertical Force, the approximate average anchor slip was determined. Then with this approximate value of anchor slip, the appropriate Anchor Drag versus Horizontal Displacement curve was used to get an approximate watch circle. This field prediction of the watch circle size was made by the engineer on site to see if it would be necessary to reset the anchors and try again. Each mooring's predicted watch circle fell below 50 feet and no anchor resetting was needed. The final step in the installation was to lower the buoy back into the water with the 45 foot chain section removed.

Unlike all standard Navy fleet moorings, these unique moorings were put through an acceptance test. A tug was secured to each buoy and a dynamometer measured the load applied in the line. The load was brought up to the design load and with this load held constant, the tug pulled approximately toward each anchor. The buoy displacement was noted using transits. The result was an average watch circle of 35 feet.

## 3. PHASE II

The same site characteristics and positioning constraints placed on the first three moorings held for these. As seen in Figure 1, these remaining moorings were bounded by the installed three. Also, the materials for Phase II were procured and on site. The 50 foot maximum watch circle at the same design load was still the main design criteria.

Phase II differed from Phase I in that the hardware was a smaller size, the placement of these three was more restricted due to the previously installed moorings and the number 3 mooring was to be installed on the side of a sloping bottom. Despite these differences the same concept was chosen.

For Phase II the TI-59 calculator was replaced by a catenary mooring program written to our specification by Presearch Inc. See Reference 2. The program is coded for a TEKTRONIX 4081 interactive graphic terminal in FORTRAN. This program has the graphic capabilities of displaying both an elevation view and a load-deflection curve for a mooring leg. The leg can have up to three different materials and two sinkers. Our program is flexible and can be used to analyze a catenary with a single leg or a compound leg using a spider plate or equalizer. Also, the program can do the analysis of a mooring on an inclined bottom. This program made it possible to drastically reduce the time required to perform the iterative calculations.

The material procured for Phase II included 9,000 pound Navy stockless anchors with stabilizers. The behavior of this particular anchor was known because the Naval Civil Engineering Laboratory (NCEL), Port Hueneme, California had performed several anchor holding experiments at Indian Island. See reference 3. This exact anchor type was one of the types used by NCEL. The data from these pull tests was used to better predict the anchor drag distances and anchor holding capacities.

Moorings number 4 and 5 were analyzed using the same procedure as in Phase I. The unknown anchor drag distance resulting from lifting the ground ring made this parametric study necessary. Like-

wise, a parametric study was done for mooring number 3 but, because of the sloping bottom, each leg had to be investigated separately.

In November 1982, we conducted a bottom investigation at mooring site number 3. This investigation consisted of a team of divers swimming down the slope and trying to push a rod into the bottom at predetermined locations. The maximum penetration was approximately one foot. A grab sample from below the loose mud revealed a sandy silt bottom. Two of the mooring's three anchors will be placed in this soil and the third anchor will be in mud.

The final design for all three remaining moorings followed a similar procedure as before. Special consideration was given to the effect of the different bottom soils and slope on the movement of mooring number 3's anchors. The fluke angles will be set to sand on two of the three anchors for mooring number 3.

At this time it is anticipated that we will use a similar installation scenario as in Phase I. This has not been finalized and depends on vessel availability.

## 4. CONCLUSION

The Navy's successful installation and acceptance test of the three moorings in Phase I proves this procedure of shortening the riser to reduce the watch circle to be effective. The installation procedure is a critical factor to consider to ensure the results are as designed. This method also results in accurate positioning of the mooring.

The design procedure can easily be accomplished with a hand held calculator such as the TI-59. However, a computer aided mooring design program such as our's saves considerable time and effort during the iterative calculations.

## 5. REFERENCES

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